The extent of strangeness equilibration in quark-gluon plasma

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Abstract

The evolution and production of strangeness from chemically equilibrating and transversely expanding quark gluon plasma which may be formed in the wake of relativistic heavy ion collisions is studied with initial conditions obtained from the Self Screened Parton Cascade (SSPC) model. The extent of partonic equilibration increases almost linearly with the square of the initial energy density, which can then be scaled with number of participants.

1 Introduction

Strangeness enhancement is one of the robust signatures of quark - hadron phase transition during the ultra relativistic heavy ion collisions [1, 2]. In heavy ion collisions strangeness is produced abundantly through the partonic interactions if the temperature $T \geq 200$ MeV, the mass threshold of this semi-heavy flavour. The extent of its equilibration would however depend upon the initial conditions and the life time of the hot deconfined phase. It has recently been shown that the chemical equilibration of the light flavours and the gluons slows down due to the radial expansion [3, 4]. It should then be expected that the extent of strangeness equilibration can also be affected if the radial expansion of the plasma is included. An early work in this direction used the initial conditions obtained from the HIJING model and considered only a longitudinal expansion [5]. In the present work, we closely follow this treatment with the initial conditions obtained from Self Screened Parton Cascade (SSPC) model [6] and extend it to include transverse expansion [7] as well. In the next section we briefly describe the hydrodynamic and chemical evolution of the plasma in a (1+1) dimensional longitudinal expansion and a (3+1) dimensional transverse expansion. A brief summary is given in Sec. 3.

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2 Hydrodynamic Expansion and Chemical Equilibration

2.1 Basic equations

We start with the assumption that the system achieves a kinetic equilibrium by the time τ_i and the chemical equilibration is assumed to proceed via gluon multiplication process ($gg \to ggg$) and quark production process ($gg \to q\bar{q}$). The expansion of the system is now controlled by the equation for conservation of energy and momentum of an ideal fluid:

$$\partial_\mu T^{\mu\nu} = 0 \ , \qquad T^{\mu\nu} = (\varepsilon + P)u^\mu u^\nu + P g^{\mu\nu} \ , \tag{1}$$

where ε is the energy density and P is the pressure measured in the rest frame of the fluid [7]. The four-velocity vector u^μ of the fluid satisfies the constraint $u^2 = -1$. We assume that the distribution functions for partons can be scaled through equilibrium distributions as

$$f_j(E_j, \lambda_j) = \lambda_j \tilde{f}_j(E_j) \quad , \tag{2}$$

where $\tilde{f}_j(E_j) = (e^{\beta E_j} \mp 1)^{-1}$ is the BE (FD) distribution for gluons (quarks), and λ_j ($j = g,\ u,\ d,\ s$) are the nonequilibrium fugacities, $E_j = \sqrt{p_j^2 + m_j^2}$, and m_j is the mass of the parton. We solve the hydrodynamic equations (1) with the assumption that the system undergoes a boost invariant longitudinal expansion along the z-axis and a cylindrically symmetric transverse expansion [8]. It is then sufficient to solve the problem for $z = 0$.

The master equations governing the chemical equilibration for the dominant chemical reactions are

$$\begin{aligned}
\partial_\mu(n_g u^\mu) &= (R_{2\to3} - R_{3\to2}) - \sum_i (R_{g\to i} - R_{i\to g}) \ , \\
\partial_\mu(n_i u^\mu) &= \partial_\mu(n_{\bar{i}} u^\mu) = R_{g\to i} - R_{i\to g},
\end{aligned} \tag{3}$$

in an obvious notation. The gain and loss term for the gluon fusion ($gg \leftrightarrow i\bar{i}$) and gluon multiplication ($gg \leftrightarrow ggg$) processes can be written as

$$R_{g\to i} - R_{i\to g} = R_2^i n_g \left(1 - \frac{\lambda_i^2}{\lambda_g^2}\right) . \tag{4}$$

$$R_{2\to3} - R_{3\to2} = R_3 n_g \left(1 - \lambda_g\right) . \tag{5}$$

Using these rate equations, Eq.(3) can now be simplified for (3+1) and (1+1) dimension accordingly [7]. For solving the eqs.(1) and (3) numerically, we use the initial conditions obtained from SSPC model [6]. In calculating the thermally averaged and velocity weighted rates, R_2^i and R_3, we have also considered the temperature dependent coupling constant, however, for details of the calculation see Ref. [7].

2.2 Results and Discussions

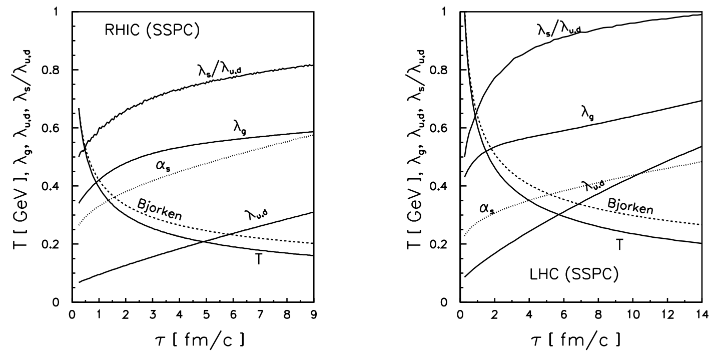

Figure 1: Variation of temperature, coupling constant, gluon and quark fugacities with proper time for (1+1) dimensional hydrodynamic expansion with SSPC initial conditions for RHIC (left) and LHC (right) energies.

In figure 1 we show our results for the longitudinal expansion for RHIC and LHC energies. We do note that the plasma is not fully chemically equilibrated at either RHIC or LHC energies. As the additional parton production consumes energy, the temperature of the partonic plasma is found to be reduced considerably faster than the ideal Bjorken's scaling ($T = T_0(\tau_0/\tau)^{1/3}$, T_0 and τ_0, respectively, are initial temperature and time of the parton gas) represented by the dashed line. We further note that the extent of equilibration for the strange quarks in comparison to that for the light quarks ($\lambda_s/\lambda_{u,d}$) rises rapidly and once the temperature falls below about 300 MeV ($\sim\ 2m_s$) it gets more or less frozen by this time.

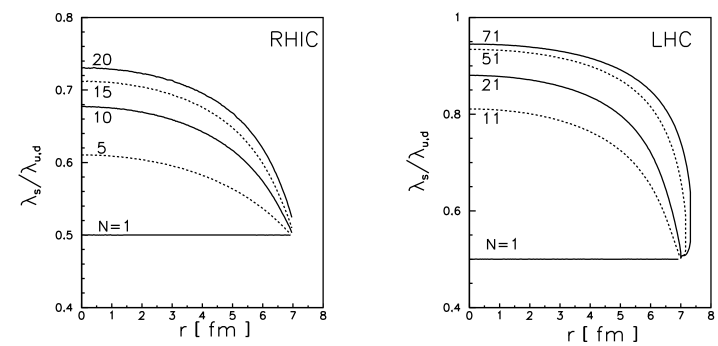

Figure 2: Variation of strange to non-strange quark fugacity ratio with the transverse radius for RHIC (left) and LHC (right) energies at different times.

In figure 2, we present our results for the radial variation of $\lambda_s/\lambda_{u,d}$ for RHIC and LHC energies, respectively, for various times along the constant energy density contours with $\tau = N\tau_0$. Here N is defined [3, 9] through $\varepsilon(r, \tau) = \varepsilon(r = 0, \tau_0)/N^{4/3}$. We see that the extent of strangeness equilibration attains its highest value near $r = 0$ and rises rapidly first and only slowly later in time, though the individual variation of differnet λ's are somewhat interesting [7]. Here also the plasma is not fully equilibrated as before.

The radial variation of the final fugacities with the initial energy density for RHIC and LHC energies are displayed in figure 3. It is interesting to note that once the energy density is beyond about 20–40 GeV, the final fugacities for all the partons increase almost linearly with the square of the energy density [7] as obtained at the CERN SPS [10] energies.

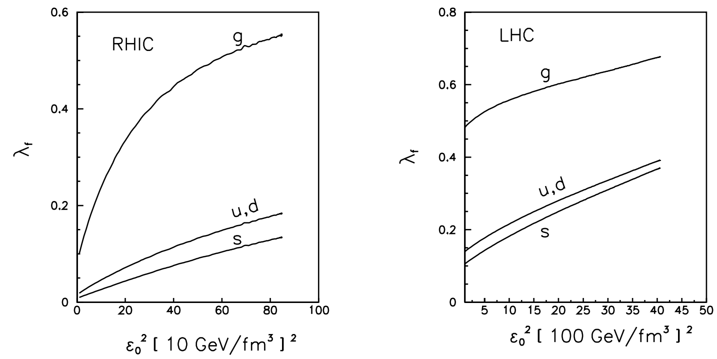

Figure 3: Variation of the final fugacities with the initial energy density for RHIC (left) and LHC (right) energies.

3 Summary

We have studied the evolution and production of strangeness from an equilibrating and transversely expanding quark gluon plasma. Initial conditions are obtained from SSPC model. We find that most of the strange quarks are produced when the temperature is still more than about 300 MeV ($\sim 2m_s$) and are not fully equilibrated. We also find approximately that the number of strange quarks produced (extent of strangeness equilibration) rises linearly with the square of the initial energy density within our approach. This may help us to obtain the scaling of the initial energy density with the number of participants.

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